AVR Beyond Arduino

This presentation is intended for people who have experience with Arduino projects and are looking to take their skills up a notch.

This presentation may serve as a stepping stone to introduce concepts that can be confusing to builders reading an AVR datasheet for the first time.

This won't make any sense to beginners and is useless to people who don't actually use Arduino to build things.

Topics

What is a Register?

Bitwise Operators - Change individuals bits within a register

Direct Port Access - Faster Digital Reads and Writes, multiple Pins simultaneously

Timer / Counter Modules

Change PWM Frequency - LEDs, Sound, Motor Drivers

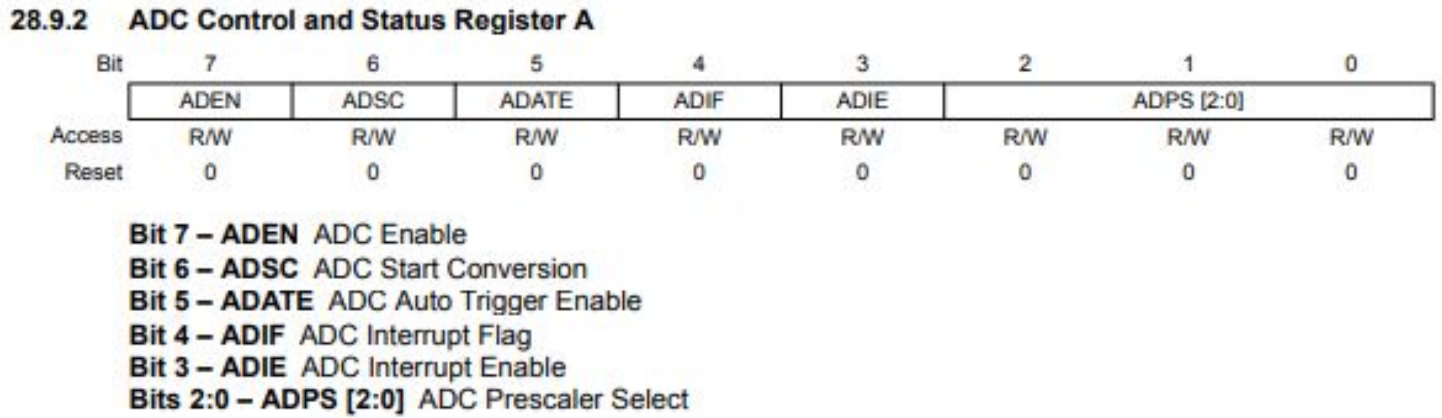
Faster Analog Read

What is a Register?

A small place where data can be stored. The data can be an instruction, a numerical value, a character, an address, a hardware setting, etc.

AVR chip registers can be complicated and difficult for beginners to understand. Standard Arduino libraries do a great job hiding all the registers and settings to be more user friendly.

AVR chips used in Arduino Uno and Mega have 8-bit registers. There are many registers full of settings that control how the chip works and can be changed by the user program.



28.9.2 ADC Control and Status Register A

Bit	7	6	5	4	3	2	1	0
	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS [2:0]		
Access	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Reset	0	0	0	0	0	0	0	0

Bit 7 – ADEN ADC Enable
Bit 6 – ADSC ADC Start Conversion
Bit 5 – ADATE ADC Auto Trigger Enable
Bit 4 – ADIF ADC Interrupt Flag
Bit 3 – ADIE ADC Interrupt Enable
Bits 2:0 – ADPS [2:0] ADC Prescaler Select

Bitwise Operators: OR, AND

Turn on a single bit using OR “ | “

```
byte myValue = B00110011 | B10000000; // answer is B10110011
```

```
    00110011
|   10000000
    10110011  Bit 7 is now on, other bits did not change
```

Turn off a single bit using AND “ & “

```
byte myValue = B00110011 & B11111110; // answer is B00110010
```

```
    00110011
&   11111110
    00110010  Bit Zero is now off, other bits stayed the same
```

Bitwise Operators: <<, >>

Shift all Bits Left <<

```
B00000100 << 1 = B00001000
    4     << 1 =     8

B11110000 << 2 = B11000000
   240    << 2 =    192
```

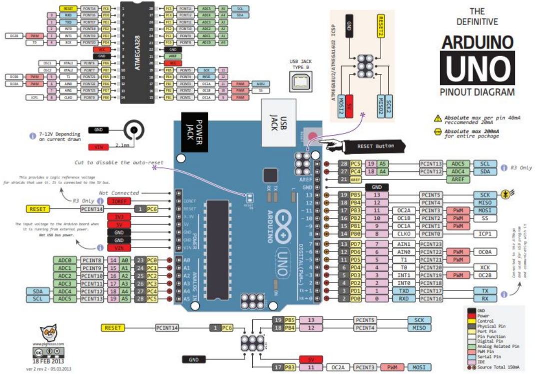
Shift all Bits Right >>

```
B00000100 >> 1 = B00000010
    4     >> 1 =     2

B00000111 >> 2 = B00000001
    7     >> 2 =     1
```

When shifting bits, bits that are equal to 1 can be dropped off the end and are lost. The extra space created when shifting is always filled in with Zeroes.

Arduino Pins vs AVR Ports/Pins



Arduino pins have numbers such as D0 to D13, A1 to A5 for the Uno.

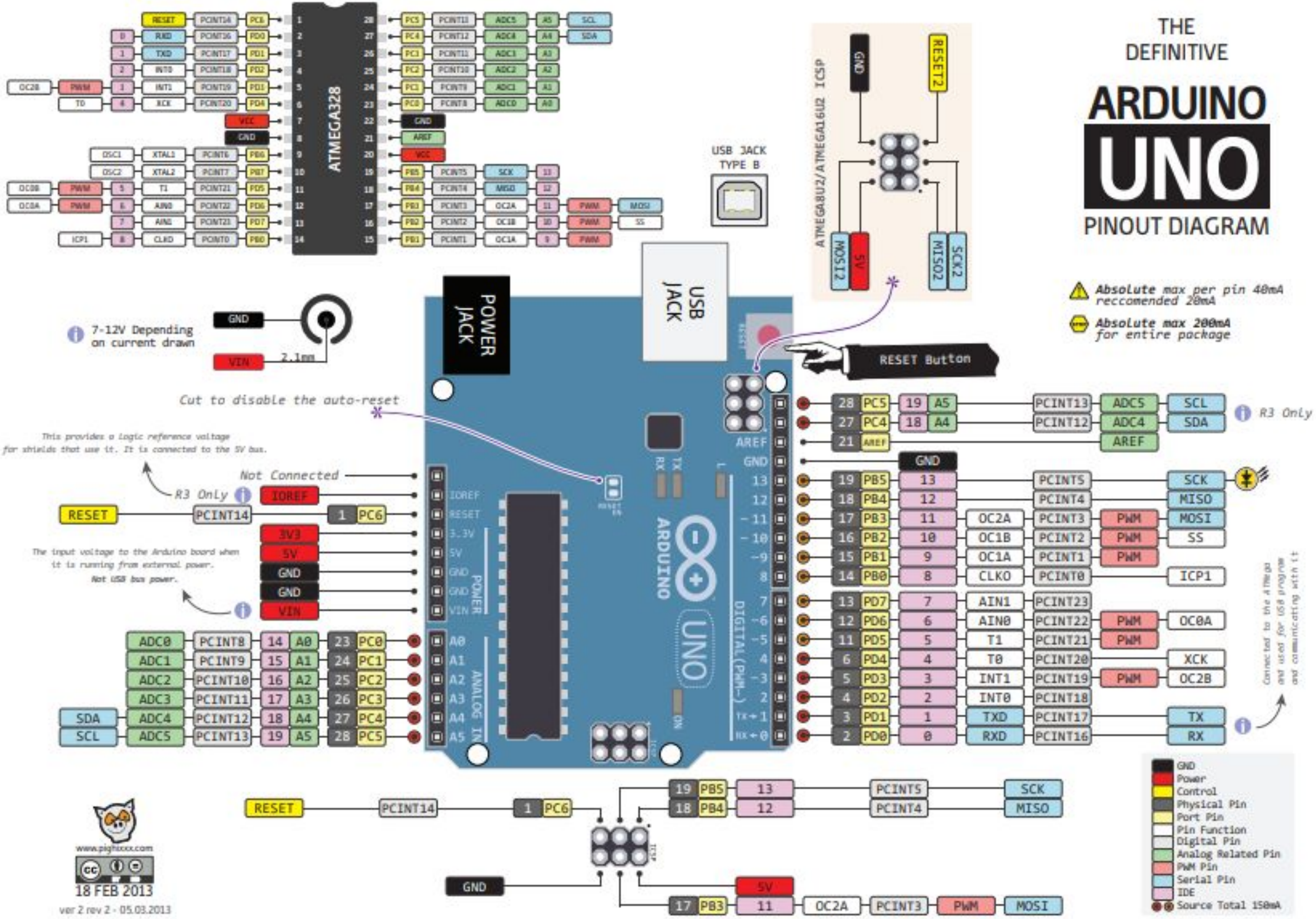
AVR uses a different numbering system. Pins are grouped together into Ports and each Port has a different letter. Each Port can have up to 8 pins, each pin having a number.
Example: PD0 = Port D, Pin 0

Different AVR chips have different features, so the AVR Port and Pin numbering changes for different chips. Arduino tries to standardize some of these basic features.

- Arduino Uno uses the Atmega328p AVR chip. The Serial RX function is on AVR pin PD0 which Arduino calls pin D0.
- Arduino Mega uses the Atmega2560 AVR chip. The Serial RX function is on AVR pin PE0 which Arduino calls pin D0.

Google search for “Arduino Uno pinout” and you can find great images showing the pin mappings for different types of Arduinos.

THE DEFINITIVE
ARDUINO UNO
PINOUT DIAGRAM



7-12V Depending on current drawn

This provides a logic reference voltage for shields that use it. It is connected to the 5V bus.

The input voltage to the Arduino board when it is running from external power. Not USB bus power.

Connected to the ATmega and used for USB programming and communicating with it

Absolute max per pin 40mA reccomended 20mA

Absolute max 200mA for entire package

- ■ GND
- 🟥 Power
- 🟨 Control
- ■ Physical Pin
- 🟨 Port Pin
- □ Pin Function
- □ Digital Pin
- 🟩 Analog Related Pin
- 🟥 PWM Pin
- 🟦 Serial Pin
- ▨ IDE
- ● ● Source Total 150mA

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Direct Port Access

Arduino functions digitalRead() and digitalWrite() are robust for beginners but quite slow. These Arduino functions have the added step of translating the Arduino pin number to the AVR pin number and also double-check a number of other things for issues. Skipping this gets the job done 40-80x faster.

Turn on Port D Pin 0:

```
PORTD = B00000001; // Turns on PD0 and turns off PD1 through PD7.

PORTD = PORTD | B00000001; // Turns on PD0. PD1 through PD7 stay the same.
```

Turn off Port B Pins 1, 3, and 5:

```
PORTB = PORTB & B11010101; // Turns off PB1,PB3,PB5. Others don’t change.
```

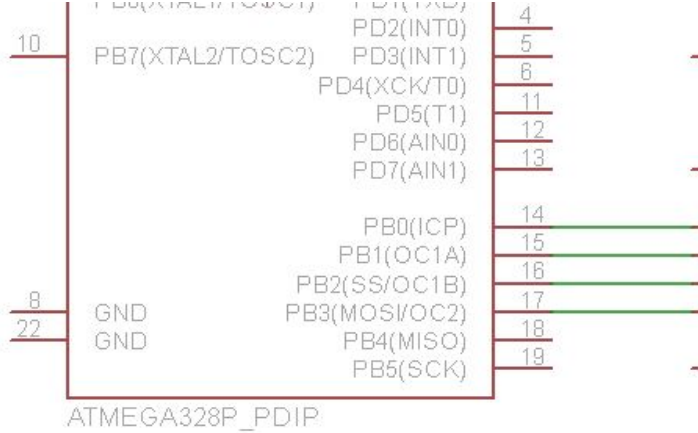
If your project requires several pins to be turned on or off at the same time, Direct Port Access allows that, while the Arduino function digitalWrite() can’t help.

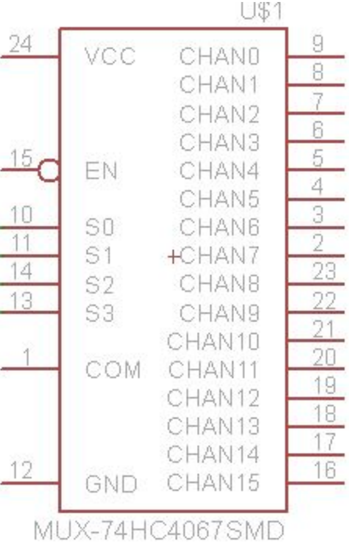
Direct Port Access

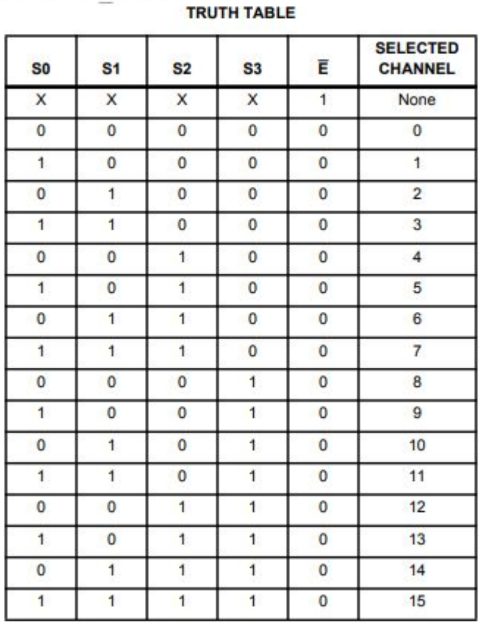
Direct port access is great if you want to expand your IO using a multiplexer. Wire up the MUX’s channel select pins to an AVR port and the channel can be selected very quickly.

The “4067” chip is a 16 channel analog mutiplexer. 4 control lines are used to select which channel is connected.

```
void SetMux(byte channel){
  PORTB &= 0B11110000; // clear bits PB0 to PB3
  PORTB |= channel; // write ch to bits PB0 to PB3
}
```







TRUTH TABLE

S0	S1	S2	S3	Ē	SELECTED CHANNEL
X	X	X	X	1	None
0	0	0	0	0	0
1	0	0	0	0	1
0	1	0	0	0	2
1	1	0	0	0	3
0	0	1	0	0	4
1	0	1	0	0	5
0	1	1	0	0	6
1	1	1	0	0	7
0	0	0	1	0	8
1	0	0	1	0	9
0	1	0	1	0	10
1	1	0	1	0	11
0	0	1	1	0	12
1	0	1	1	0	13
0	1	1	1	0	14
1	1	1	1	0	15

Direct Port Access

The PINx registers can be used to read 8 digital inputs at once, replacing digitalRead().

Whenever a PINx register is read, all pins of that port are read at the same time, even if they are set as an output. If you only want to read a single pin, discard the values you don't care about.

```
myValue = PIND; // Reads PortD pins 0 through 7

myValue = PIND & B00000001; // Reads PortD D0 through D7, D1 through D7 are discarded

myValue = (PINB & B00001000) >> 3; // Reads PortB pin 3.
```

Direct Port Access

Don’t forget to set the direction of each Pin. Arduino does this using the pinMode() function. For AVR, directly accessing the DDRn register can speed things up.

Set Port D Pin 0 as an output:

```
DDRD = DDRD | B00000001; // Set pin 0 as output, other pins unaffected
```

Set PortB Pins 1, 3, and 5 as input:

```
DDRB = DDRB & B11010101; // Sets pins 1,3,5 as inputs, other pins unaffected
```

If a particular pin in your project is changing direction of pins very often, then using the DDRn registers can speed up your program.

If a pin’s direction is only setup once at the beginning of your program and never changes again, then it’s probably better to use the Arduino pinMode() function.

Direct Port Access

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Timer/Counter Modules

Multipurpose hardware inside the AVR that can perform a variety of functions such as:

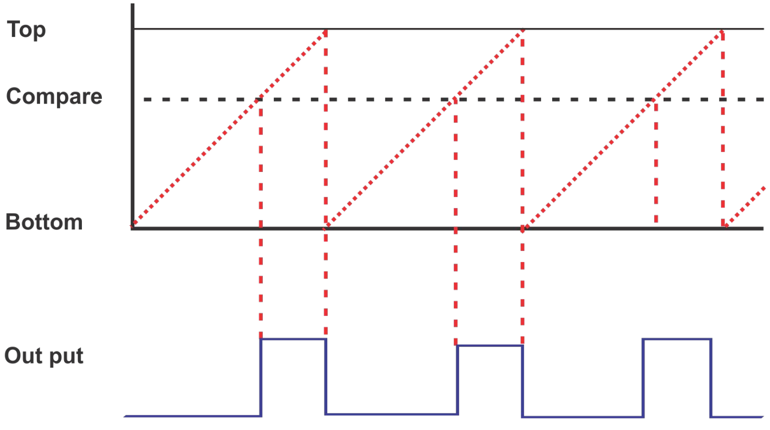
- Generating PWM signals: Frequency, Duty Cycle - analogWrite()
- Keeping track of time - delay(), millis()
- Generating interrupts to run a function at a specific time interval
- Counting pulses

Uno has 3 Timer/Counters

Mega has 6 Timer/Counters

Each Timer/Counter is controlled using a number of different registers such as:
Settings: TCCRnx, OCRnx, TIMSKn
Counter: TCNTn
Outputs: OCnx, TIFRn

Counters can be 8 bit (0-255) or 16 bit (0-65535)



AVR Timer

Timer/Counter Pin Mapping

Each Timer/Counter module is connected to specific pins.

For Atmega328p / Arduino Uno:

Timer	Arduino Pins	AVR Pins
0	6, 5	PD6,PD5
1	9, 10	PB1,PB2
2	11, 3	PB3,PD3

For Atmega2560 / Arduino Mega:

Timer	Arduino Pins	AVR Pins
0	13, 4	PB7,PG5
1	12, 11	PB6,PB5
2	10, 9	PB4,PH6
3	5, 3, 2	PE3,PE5,PE4
4	8, 7, 6	PH5,PH4,PH3

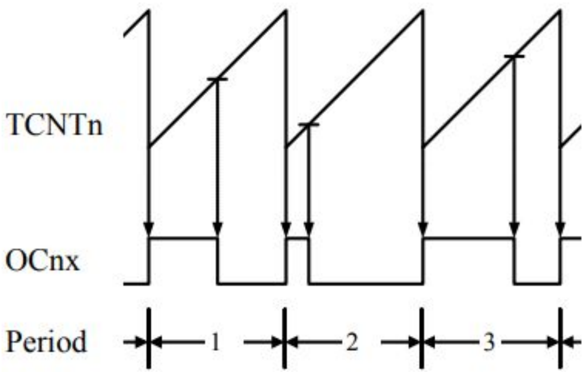
Good references from Arduino:
https://www.arduino.cc/en/Tutorial/SecretsOfArduinoPWM
https://playground.arduino.cc/Main/TimerPWMCheatsheet

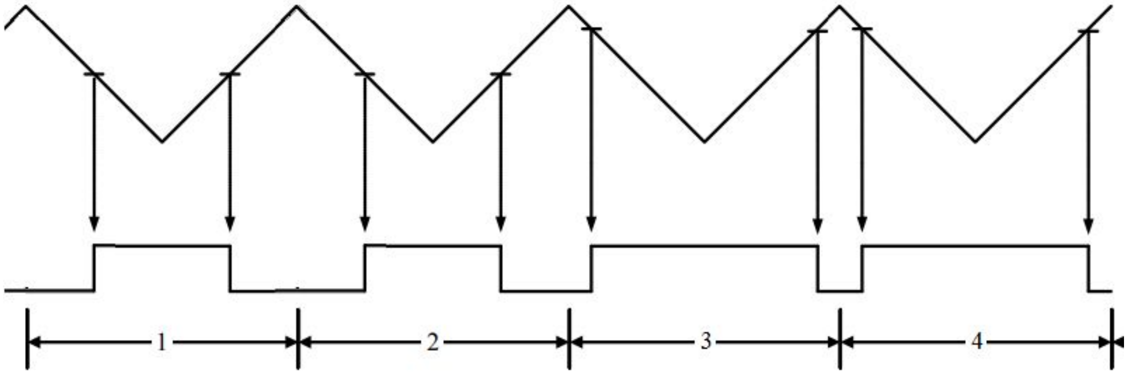
PWM Modes

AVR Counters have different modes of counting. This results in different PWM signals being generated.

Fast PWM only counts up, and rolls-over at the top creating a sawtooth wave. The front edges of each PWM pulse are equally spaced.

Phase Correct PWM counts up and down creating a triangle wave. The middle of each PWM pulse is equally spaced.





For applications like blinky LEDs, servos, and motor drivers, the choice of PWM mode generally doesn’t matter other than it cuts the PWM frequency in half.

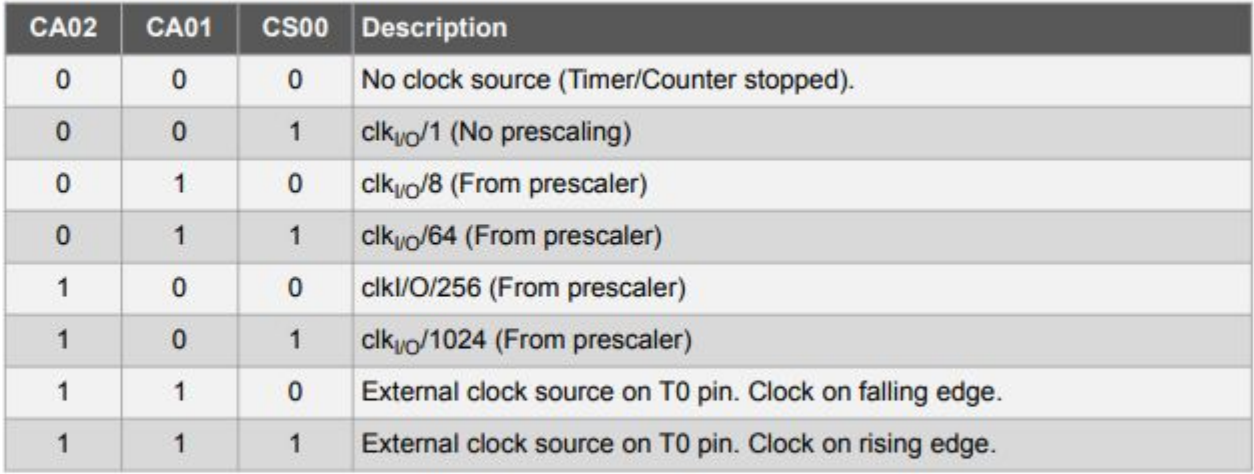
By default, Arduino operates all the Timers in Fast PWM mode.

Clock Source

Every counter has its own clock. The counter increments or decrements once for every tick of the “clock”. The clock source may be the main system clock (16MHz crystal) or an external clock source coming from a pin.

The clock source can be changed using the Clock Select bits of the TCCRnB register. These vary slightly from one Timer to another. Not all Timers are capable of having an external clock source. Different timers have different prescaler options available.

ATmega328p Timer0 Clock Source Options:



CA02	CA01	CS00	Description	
0	0	0	No clock source (Timer/Counter stopped).	Off
0	0	1	$\text{clk}_{I/O}$/1 (No prescaling)	Same as XTAL (16 MHz)
0	1	0	$\text{clk}_{I/O}$/8 (From prescaler)	⅛ of 16 MHz = 2 MHz
0	1	1	$\text{clk}_{I/O}$/64 (From prescaler)	1/64 of 16 MHz = 250 kHz
1	0	0	clkI/O/256 (From prescaler)	1/256 of 16 MHz = 62.5 kHz
1	0	1	$\text{clk}_{I/O}$/1024 (From prescaler)	1/1024 of 16 MHz = 15.6 kHz
1	1	0	External clock source on T0 pin. Clock on falling edge.	Pin T0 = PD4 = Arduino D4
1	1	1	External clock source on T0 pin. Clock on rising edge.	

Change PWM Frequency using Prescaler

When using the internal clock source, the Timer/Counter clock is equal to the system clock (16 MHz) divided by a selected Prescaler value.

Every tick of the Timer's clock increments the Counter by 1 until it reaches its size limit (256 for 8-bit counter)

PWM Frequency = System Clock / Prescaler / Counter Size = 16 MHz / 64 / 256 = 976.56 Hz

Bits 0 to 2 of the TCCRnB Register set the Prescaler factor

```
TCCR0B = TCCR0B & B11111000 | B00000011; // set timer 0 prescaler to 64 for 976.56 Hz
```

Setting prescaler to 1, Timer Clock = System Clock. PWM Frequency = 16 MHz / 1 / 256 = 62.5 kHz

```
TCCR0B = TCCR0B & B11111000 | B00000001; // set timer 0 prescaler to 1 for 62500 Hz
```

Prescalers options are defined in the datasheet and allow coarse adjustment of the frequency.

Not all Timers have the same prescaler options available, check datasheet for details.

Set Prescalers - ATMEGA328p (Uno,Nano)

```
//------------------------------ Set PWM frequency for D5 & D6 using Timer0 ------------------------------
TCCR0B = TCCR0B & B11111000 | B00000001;  // set timer 0 divisor to     1 for PWM frequency of 62500.00 Hz
TCCR0B = TCCR0B & B11111000 | B00000010;  // set timer 0 divisor to     8 for PWM frequency of  7812.50 Hz
TCCR0B = TCCR0B & B11111000 | B00000011;  // set timer 0 divisor to    64 for PWM frequency of   976.56 Hz Default
TCCR0B = TCCR0B & B11111000 | B00000100;  // set timer 0 divisor to   256 for PWM frequency of   244.14 Hz
TCCR0B = TCCR0B & B11111000 | B00000101;  // set timer 0 divisor to  1024 for PWM frequency of    61.04 Hz

//------------------------------ Set PWM frequency for D9 & D10 using Timer1 ------------------------------
TCCR1B = TCCR1B & B11111000 | B00000001;  // set timer 1 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR1B = TCCR1B & B11111000 | B00000010;  // set timer 1 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR1B = TCCR1B & B11111000 | B00000011;  // set timer 1 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR1B = TCCR1B & B11111000 | B00000100;  // set timer 1 divisor to   256 for PWM frequency of   122.55 Hz
TCCR1B = TCCR1B & B11111000 | B00000101;  // set timer 1 divisor to  1024 for PWM frequency of    30.64 Hz

//------------------------------ Set PWM frequency for D3 & D11 using Timer 2 ------------------------------
TCCR2B = TCCR2B & B11111000 | B00000001;  // set timer 2 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR2B = TCCR2B & B11111000 | B00000010;  // set timer 2 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR2B = TCCR2B & B11111000 | B00000011;  // set timer 2 divisor to    32 for PWM frequency of   980.39 Hz
TCCR2B = TCCR2B & B11111000 | B00000100;  // set timer 2 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR2B = TCCR2B & B11111000 | B00000101;  // set timer 2 divisor to   128 for PWM frequency of   245.10 Hz
TCCR2B = TCCR2B & B11111000 | B00000110;  // set timer 2 divisor to   256 for PWM frequency of   122.55 Hz
TCCR2B = TCCR2B & B11111000 | B00000111;  // set timer 2 divisor to  1024 for PWM frequency of    30.64 Hz
```

Set Prescalers - ATMEGA2560 (Mega)

```
//------------------------------ Set PWM frequency for D4 & D13 ------------------------------
TCCR0B = TCCR0B & B11111000 | B00000001;  // set timer 0 divisor to     1 for PWM frequency of 62500.00 Hz
TCCR0B = TCCR0B & B11111000 | B00000010;  // set timer 0 divisor to     8 for PWM frequency of  7812.50 Hz
TCCR0B = TCCR0B & B11111000 | B00000011;  // set timer 0 divisor to    64 for PWM frequency of   976.56 Hz Default
TCCR0B = TCCR0B & B11111000 | B00000100;  // set timer 0 divisor to   256 for PWM frequency of   244.14 Hz
TCCR0B = TCCR0B & B11111000 | B00000101;  // set timer 0 divisor to  1024 for PWM frequency of    61.04 Hz

//------------------------------ Set PWM frequency for D11 & D12 -----------------------------
TCCR1B = TCCR1B & B11111000 | B00000001;  // set timer 1 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR1B = TCCR1B & B11111000 | B00000010;  // set timer 1 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR1B = TCCR1B & B11111000 | B00000011;  // set timer 1 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR1B = TCCR1B & B11111000 | B00000100;  // set timer 1 divisor to   256 for PWM frequency of   122.55 Hz
TCCR1B = TCCR1B & B11111000 | B00000101;  // set timer 1 divisor to  1024 for PWM frequency of    30.64 Hz

//------------------------------ Set PWM frequency for D9 & D10 ------------------------------
TCCR2B = TCCR2B & B11111000 | B00000001;  // set timer 2 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR2B = TCCR2B & B11111000 | B00000010;  // set timer 2 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR2B = TCCR2B & B11111000 | B00000011;  // set timer 2 divisor to    32 for PWM frequency of   980.39 Hz
TCCR2B = TCCR2B & B11111000 | B00000100;  // set timer 2 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR2B = TCCR2B & B11111000 | B00000101;  // set timer 2 divisor to   128 for PWM frequency of   245.10 Hz
TCCR2B = TCCR2B & B11111000 | B00000110;  // set timer 2 divisor to   256 for PWM frequency of   122.55 Hz
TCCR2B = TCCR2B & B11111000 | B00000111;  // set timer 2 divisor to  1024 for PWM frequency of    30.64 Hz
```

Set Prescalers - ATMEGA2560 (Mega)

```
//------------------------------ Set PWM frequency for D2, D3 & D5 ---------------------------
TCCR3B = TCCR3B & B11111000 | B00000001;  // set timer 3 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR3B = TCCR3B & B11111000 | B00000010;  // set timer 3 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR3B = TCCR3B & B11111000 | B00000011;  // set timer 3 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR3B = TCCR3B & B11111000 | B00000100;  // set timer 3 divisor to   256 for PWM frequency of   122.55 Hz
TCCR3B = TCCR3B & B11111000 | B00000101;  // set timer 3 divisor to  1024 for PWM frequency of    30.64 Hz

//------------------------------- Set PWM frequency for D6, D7 & D8 ---------------------------
TCCR4B = TCCR4B & B11111000 | B00000001;  // set timer 4 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR4B = TCCR4B & B11111000 | B00000010;  // set timer 4 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR4B = TCCR4B & B11111000 | B00000011;  // set timer 4 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR4B = TCCR4B & B11111000 | B00000100;  // set timer 4 divisor to   256 for PWM frequency of   122.55 Hz
TCCR4B = TCCR4B & B11111000 | B00000101;  // set timer 4 divisor to  1024 for PWM frequency of    30.64 Hz

//------------------------------- Set PWM frequency for D44, D45 & D46 ------------------------
TCCR5B = TCCR5B & B11111000 | B00000001;  // set timer 5 divisor to     1 for PWM frequency of 31372.55 Hz
TCCR5B = TCCR5B & B11111000 | B00000010;  // set timer 5 divisor to     8 for PWM frequency of  3921.16 Hz
TCCR5B = TCCR5B & B11111000 | B00000011;  // set timer 5 divisor to    64 for PWM frequency of   490.20 Hz Default
TCCR5B = TCCR5B & B11111000 | B00000100;  // set timer 5 divisor to   256 for PWM frequency of   122.55 Hz
TCCR5B = TCCR5B & B11111000 | B00000101;  // set timer 5 divisor to  1024 for PWM frequency of    30.64 Hz
```

PWM Frequency Fine Tuning

The Arduino Tone() library allows you to choose an exact frequency, but the duty cycle is fixed at 50%.

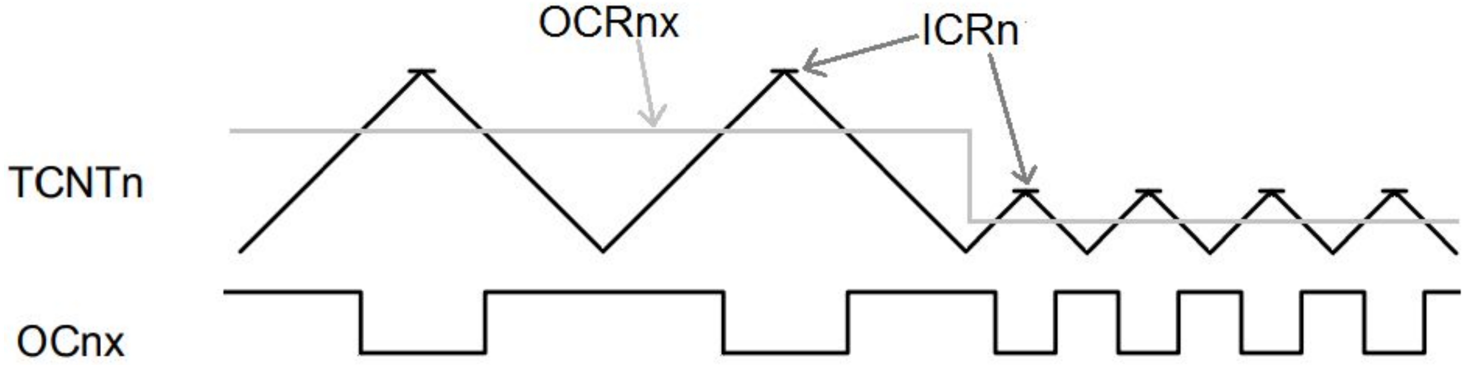
Some Timers allow precise control of both Frequency and Duty Cycle.

- Atmega328p: Timer 1 using Uno/Nano pins 9 (OC1A) and 10 (OC1B).
- Atmega2560: Timers 1; 3; 4; 5. Mega pins 11,12; 2,3,5; 6,7,8; 44,45,46; respectively

These are all 16-bit Timer/Counters - they count from 0 up to 65535 (2^{16} - 1)

In Waveform Generation Mode 10, the TOP of the counter is no longer 65535, it is whatever you set it to using register ICRx. Changing the value in ICRx allows a specific frequency to be dialed in.

The OCRnx registers are still used to set the duty cycle, but must be less than the value of ICRx



Waveform Generation Modes

WGM options vary for different timers.

16 bit timers like Timer 1 on the ATmega328p (Arduino Uno) and Timers 1, 3 and 4 on the Mega2560 offer many options.

Check the datasheet for your AVR chip to see what options are available for each Timer.

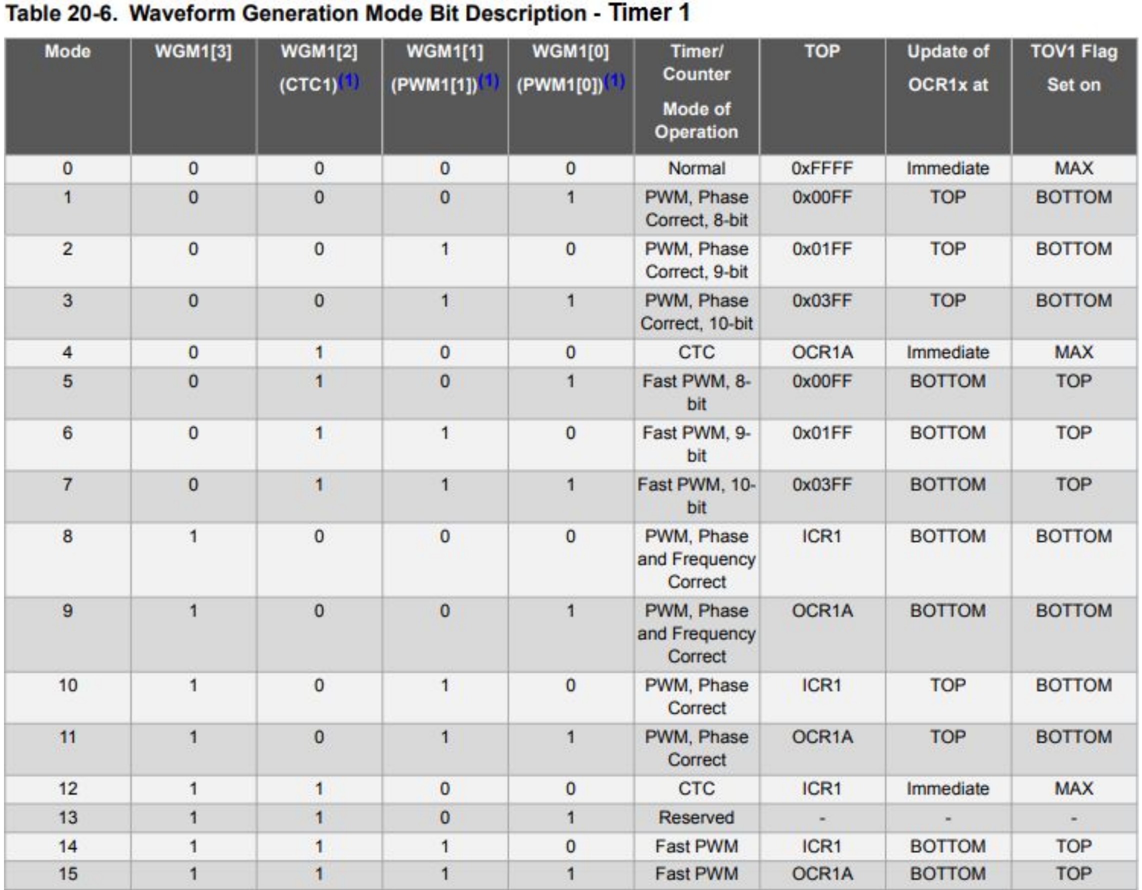


Table 20-6. Waveform Generation Mode Bit Description - Timer 1

Mode	WGM1[3]	WGM1[2] (CTC1)(1)	WGM1[1] (PWM1[1])(1)	WGM1[0] (PWM1[0])(1)	Timer/ Counter Mode of Operation	TOP	Update of OCR1x at	TOV1 Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCR1A	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICR1	BOTTOM	BOTTOM
9	1	0	0	1	PWM, Phase and Frequency Correct	OCR1A	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICR1	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCR1A	TOP	BOTTOM
12	1	1	0	0	CTC	ICR1	Immediate	MAX
13	1	1	0	1	Reserved	-	-	-
14	1	1	1	0	Fast PWM	ICR1	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCR1A	BOTTOM	TOP

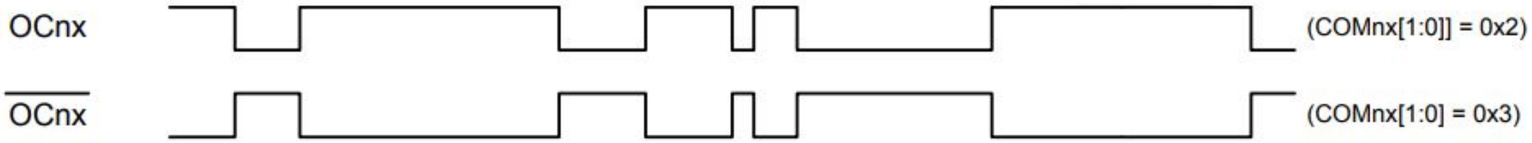
Timer1 Example Code - 20 kHz

```
void setup() {
  // Configure Timer 1 for PWM @ Alternate Frequency
  TCCR1A = B10100010; // Set WGM to Mode 10 (Phase Correct PWM), Set COM1A1 and COM1B1 (Non-Inverted PWM on Ch A and B)
  TCCR1B = B00010001; // Set WGM to Mode 10 (Phase Correct PWM), Set CS10 (Prescaler = 1)
  ICR1   = 400;       // Freq = System Clock / Prescaler / Counter TOP / 2 = 16 MHz / 1 / 400 / 2 = 20kHz
  TCNT1  = 0;         // reset counter to 0

  // Set the PWM pins as output.
  pinMode( 9, OUTPUT);
  pinMode(10, OUTPUT);
}

void loop() {
  myAnalogWrite( 9, 320); // 320/400 = 80% duty cycle
  myAnalogWrite(10,  80); //  80/400 = 20% duty cycle
}

void myAnalogWrite(int pin, int value) { // Sets the duty cycle for pins 9 and 10
  if (pin ==  9) OCR1A = value;
  If (pin == 10) OCR1B = value;
}
```

Take a look a the Arduino Playground library for Timer1: https://playground.arduino.cc/Code/Timer1

Complimentary PWM

Some applications call for two PWM pins to have the same frequency and duty cycle with one pin inverted.



This can be useful for driving an H-Bridge circuit connected to a motor, speaker, etc.

The COMnx[1:0] bits in the TCCRnA register can be used to set the PWM pin output to normal or inverted mode

```
// Set TCCR1A bit 6 (COM1A0) to 1 and bit 7 (COM1A1) to 1 so that OC1A (Arduino Pin 9) is inverted
TCCR1A = (TCCR1A & 0b00111111) | 0b11000000;

// Set TCCR1A bit 4 COM1B0) to 0 and bit 5 (COM1B1) to 1 so that OC2A (Arduino Pin 10) is non-inverted
TCCR1A = (TCCR1A & 0b11001111) | 0b00100000;

TCCR1B = (TCCR1B & 0b11111000) | 0b00000001; // Set the prescaler
TCCR1A = (TCCR1A & 0b11111100) | 0b00000010; // Set the PWM Mode, can use Phase-Correct PWM or Fast-PWM Mode
TCCR1B = (TCCR1B & 0b11100111) | 0b00010000; // Set the PWM Mode, can use Phase-Correct PWM or Fast-PWM Mode
ICR1  = 400; // PWM Mode is set to Mode 10, so we use ICR1 registers to set the frequency. 16 MHz / 1 / 400 / 2 = 20kHz
OCR1A = 300; // Set the duty cycle for OC1A (Pin 9) to a value between 0 and 400
OCR1B = OCR1A; // Set the duty cycle for OC1B (Pin 10) to be the same as Pin 9
```

Timer Limitations

Timers are a powerful but limited resource. It's possible that two Libraries try to use a single timer - one or both will have problems. When using a library, find out if it uses any Timers.

- The millis() and delay() functions use Timer0. If Timer0 is changed from the default 976.56 Hz, then millis() and delay() will not do what you expect them to. If you change the WGM of Timer0, calling either function can hang your program.

- The servo() library uses Timer1 and disables PWM functionality on the associated PWM pins. If using Mega2560 and >24 servos, Timers 3 and 4 may also be affected.
  - https://www.arduino.cc/en/Reference/servo

- The tone() library uses Timers. It starts with Timer2 but can generate multiple tones by taking over several timers.
  - https://www.arduino.cc/reference/en/language/functions/advanced-io/tone/
  - https://github.com/bhagman/Tone#ugly-details

Faster Analog to Digital Conversion (ADC)

The ADC module has a clock source that is connected to the 16 MHz system clock by a prescaler. Changing the value of the prescaler changes how much time it takes to complete an A-D conversion

Per the manufacturer’s recommendation, Arduino libraries set the ADC prescaler to 128 so the ADC clock runs at 16 MHz / 128 = 125 kHz. One ADC conversion cycle takes 13 ticks of the ADC clock.

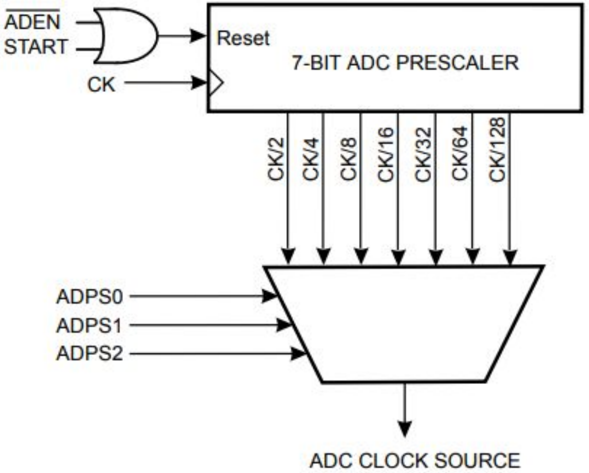
ADC Sample Rate = System Clock / ADC Prescaler / 13 = 16 MHz / 128 / 13 = ***9615*** *Hz default sample rate*
ADC Sample Time = 1 / Sample Rate = 104 micro-seconds

The default prescaler of 128 used by Arduino maximizes the accuracy of the ADC but is the slowest available option.

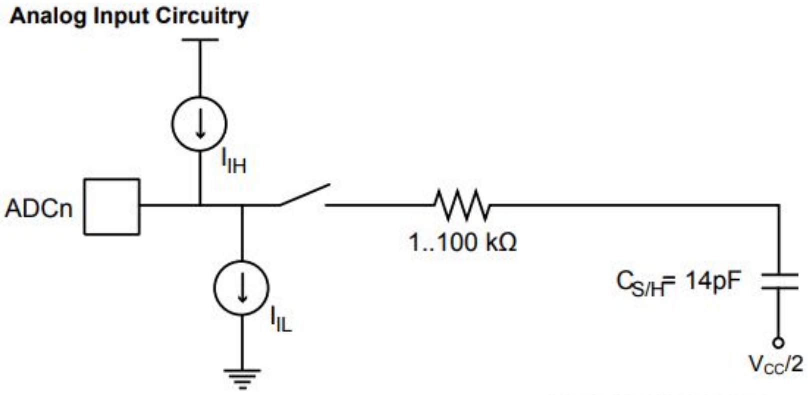
Faster conversions can be achieved by reducing the prescaler. Setting the prescaler to 64 doubles the conversion speed and is quite safe for most applications.

```
// In the setup() function...
ADCSRA = ADCSRA & B11111000 | B00000110; // Set ADC prescaler to 64
```

Even faster conversion speeds are possible but there is a catch...



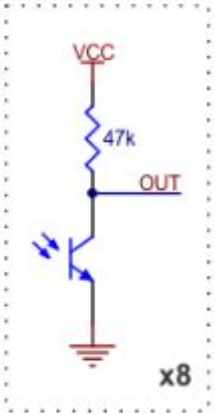
Analog Source Impedance



The ADC module uses a sample and hold capacitor that needs to be charged by the analog input. It takes time to charge this capacitor. Speeding up the ADC clock rate reduces the amount of time spent charging and can result in inaccurate readings.

Analog input sources with an impedance of 10k ohm or less are ideal.

For example, the popular QTR-8A line following sensor from Pololu has an output impedance of 47k ohm. This is above the 10k ohm recommended for best performance.



Pololu QTR-8A Line Sensor Output Circuit

The good news is that most robots don't require 10-bit accuracy from every sensor. If you only need ~6 bits of accuracy, crank up the ADC clock to 1 MHz and don't worry about it.

Even Faster Analog to Digital Conversion (ADC)

There are two options for speeding up the ADC clock while maintaining quality of the readings

```
 // First, put this in your setup() function to set the prescaler
  ADCSRA = ADCSRA & B11111000 | B00000100; // Set ADC prescaler to 16 - ADC clock is 1 MHz
```

Option 1: Call analogRead() twice, disregard first reading

```
 // Whenever reading an analog voltage in your program, read twice like this...
analogRead(sensorPin); // don’t do anything with the first reading
int mySensor = analogRead(sensorPin); // keep the second reading
```

Option 2: Replace analogRead() with your own custom function with extra delay for charging capacitor

```
int myAnalogRead(uint8_t pin){
#if defined(ADCSRB) && defined(MUX5)
  ADCSRB = (ADCSRB & ~(1 << MUX5)) | (((pin >> 3) & 0x01) << MUX5); // This is for the Mega, A8 to A15
#endif
  ADMUX = (0x01 << 6) | (pin & 0x07);
  delayMicroseconds(10); // Extra Delay Here. Test to figure out how little you can get away with.
  sbi(ADCSRA, ADSC);
  while (bit_is_set(ADCSRA, ADSC));
  uint8_t low  = ADCL;
  return (ADCH << 8) | low;
}
```

Measure VCC using internal 1.1V Reference

Atmega328p and Atmega2560 have an internal 1.1V reference that can be read by the ADC. When powering the AVR directly from a 3.3 to 5V battery, we can use this reference voltage to back-calculate the battery’s voltage on VCC.

```
uint32_t readVcc() {  // Read 1.1V reference against AVcc
  // set the reference to Vcc and the measurement to the internal 1.1V reference
  ADMUX = _BV(REFS0) | _BV(MUX3) | _BV(MUX2) | _BV(MUX1);
  delay(4); // Wait for Vref to settle
  ADCSRA |= _BV(ADSC); // Start first conversion. First conversion is not saved.
  while (bit_is_set(ADCSRA,ADSC)); // wait for measurement to complete
  ADCSRA |= _BV(ADSC); // Start second conversion.
  while (bit_is_set(ADCSRA,ADSC)); // wait for measurement to complete
  uint8_t low  = ADCL; // must read ADCL first - it then locks ADCH
  uint8_t high = ADCH; // unlocks both
  uint32_t result = (high<<8) | low;
  const float internalRef = 1.1; // The internal 1.1V ref is rated for +/- 10% accuracy. This can be manually
calibrated for each AVR chip if more accuracy is needed.
  // Conversion Factor to Calculate Vcc (in mV); 1125300 = 1.1*1023*1000
  const uint32_t scale_constant = internalRef * 1023 * 1000;
  result = scale_constant / result; // Calculate Vcc (in mV); 1125300 = 1.1*1023*1000
  return result; // Vcc in millivolts
}
```

Further Investigation

Inspect the Arduino’s user-friendly functions by searching your Arduino folder for the following files:

Default settings and timing functions: wiring.c
Digital functions: wiring_digital.c
Analog functions: wiring_analog.c

Was this useful?

Potential Future Topics:

Measuring how long code takes to run

Avoiding Division

Using I2C and/or Serial to communicate from one Arduino to another

Storing data in EEPROM

Low Power modes